

# Exceptional Electron Transport Properties of In-rich InGaN

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## 1. Introduction

Recent years have seen an explosion of interest in the narrow band gap end of the InGaN alloy system, particularly in InN. The existence of surface electron accumulation and a tendency for n-type conductivity have been well-established and are explained by an extremely large electron affinity and the location of the Fermi level stabilization energy ( $E_{FS}$ ) high in the conduction band [1]. These characteristics pose significant challenges to the integration of In-rich InGaN into devices and demonstrate the need for a better understanding of the relationship between native defects and electronic transport in the alloy system.

It has been previously shown that high-energy particle irradiation can predictably control the electronic properties of In-rich InGaN [1]. With increasing irradiation dose, the electron concentration ( $n$ ) increases and the electron mobility ( $\mu$ ) decreases until the Fermi level reaches  $E_{FS}$ , which is the saturation point. The value of  $n$  at saturation decreases with decreasing In fraction, due to the raising of the conduction band edge with respect to  $E_{FS}$ .

## 2. Results and Discussion

MBE-grown InN and In-rich InGaN films were irradiated with 2 MeV He<sup>+</sup> ions at fluences from  $1 \times 10^{14}$  -  $4 \times 10^{15}$  cm<sup>-2</sup>, followed by rapid thermal annealing treatments for 10 - 300 seconds at temperatures from 375 - 500°C. In InN, two distinct stages in the annealing process can be seen for films irradiated with  $\leq 2 \times 10^{15}$  He<sup>+</sup> cm<sup>-2</sup>. At first,  $n$  decreases (by a factor of ~2) and  $\mu$  roughly doubles. Unexpectedly,  $\mu$  increases up to a factor of 2 further in the second stage (annealing temperatures > 425°C), while there is no significant change in  $n$ . For  $n \sim 10^{19}$  cm<sup>-3</sup>, such treatments have created films with significantly higher  $\mu$  than as-grown films with comparable  $n$ .

Modeling of the concentration dependence of  $\mu$  indicates that scattering by triply charged vacancy donors is the dominant factor limiting  $\mu$  in irradiated InN samples. The first annealing stage eliminates a fraction of these vacancies, which is typical for defect annealing in semiconductors. The unusual increase in  $\mu$  observed in the second stage is discussed in terms of a spatial ordering of the remaining triply charged vacancy donors, driven by the strong electrostatic repulsion between them. Ordering of the charged defects does not change  $n$  but strongly reduces the electron scattering rates. This may be the first experimental observation of improvements of the charged transport due to the diffusion of charged defects into an ordered lattice.

In the In-rich InGaN alloys, the effects of the second annealing stage become less apparent, and  $\mu$  does not increase as much as has been seen in InN. This behavior can be explained by the smaller range of  $n$  resulting from the closer location of  $E_{FS}$  to the conduction band edge. Also the effects of the defect ordering are not as pronounced since  $\mu$  is strongly reduced by the alloy disorder scattering.

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## References

[1] S.X. Li, et al., Phys. Rev. B **71** (16), 161201 (2005).

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Summary of the abstract	Irradiation of In-rich InGaN films with 2 MeV He+ particles followed by rapid thermal annealing is shown to create remarkably large increases in electron mobility and smaller decreases in electron concentration. These changes are explained by partial defect annihilation as well as ordering of the remaining charged defects. The maximum mobility values decrease with decreasing In fraction, due to alloy disorder scattering and a decreased electron concentration.
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